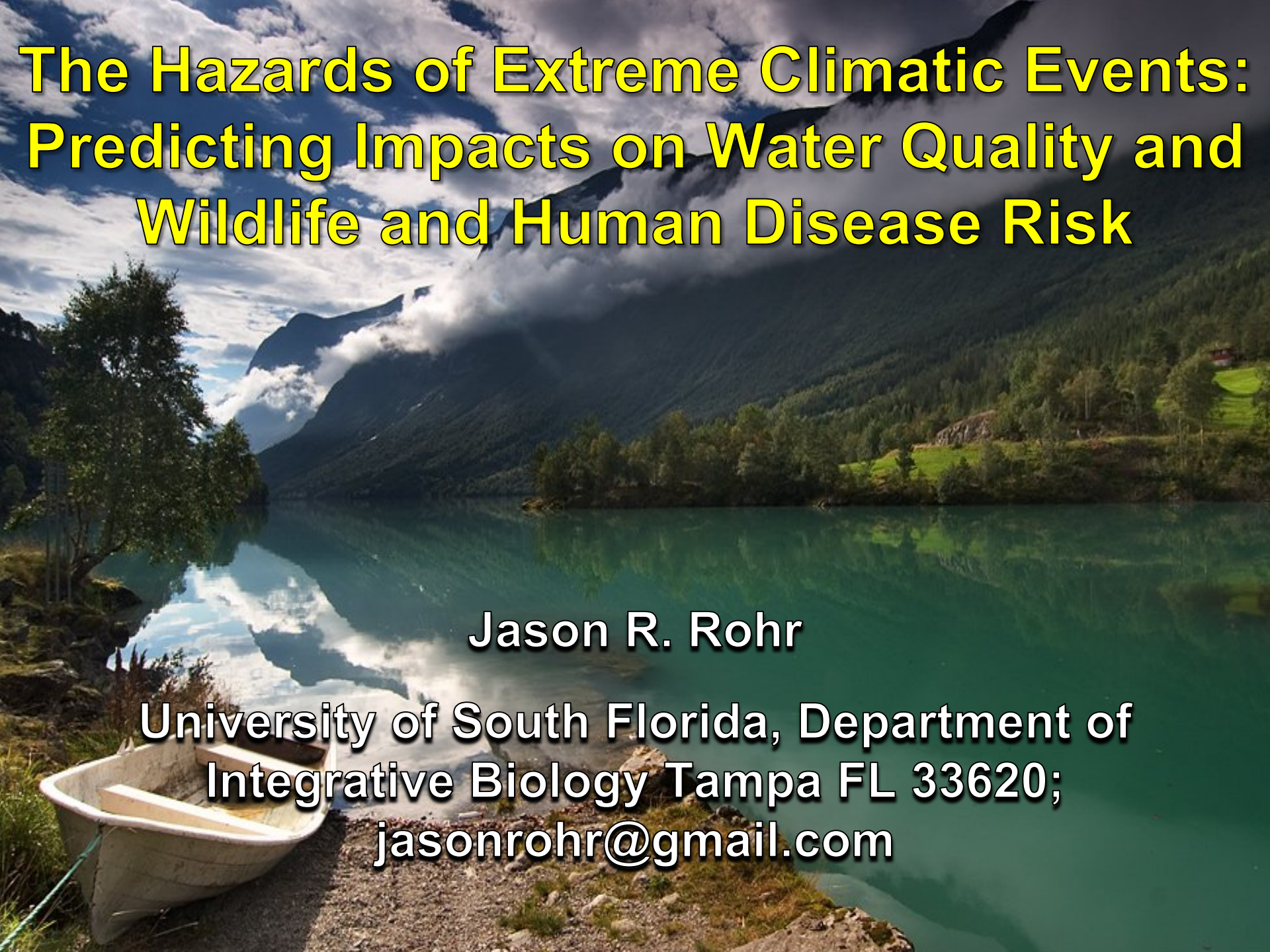

The Hazards of Extreme Climatic Events: Predicting Impacts on Water Quality and Wildlife and Human Disease Risk

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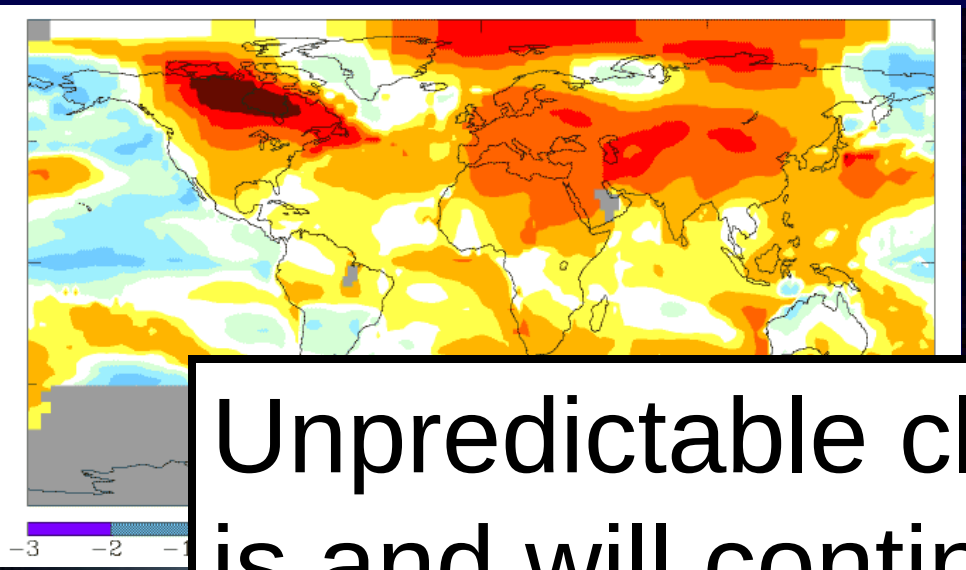
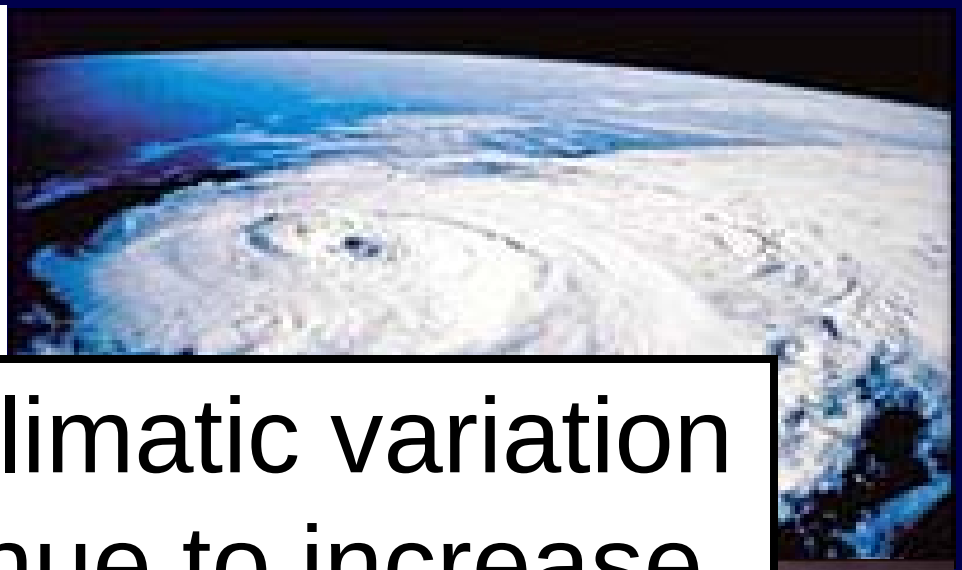
Global Climate Change and Extremes

- Well established that GCC is affecting climatic variability and extremes
- Climatic variability and extremes are inextricably linked
  - change in the variance of a distribution produces a larger change in the frequency of the extremes than a change to the mean
  - El Niño becoming more intense and frequent

Climate Change





Unpredictable climatic variation is and will continue to increase

Water Quality

- Extreme climatic events have already had societal impacts on air and water quality
  - wildfires, energy demand, water supply, pollution, pathogens, ecosystem services
- Importance of understanding how extremes affect air and water quality, and consequently wildlife and human health

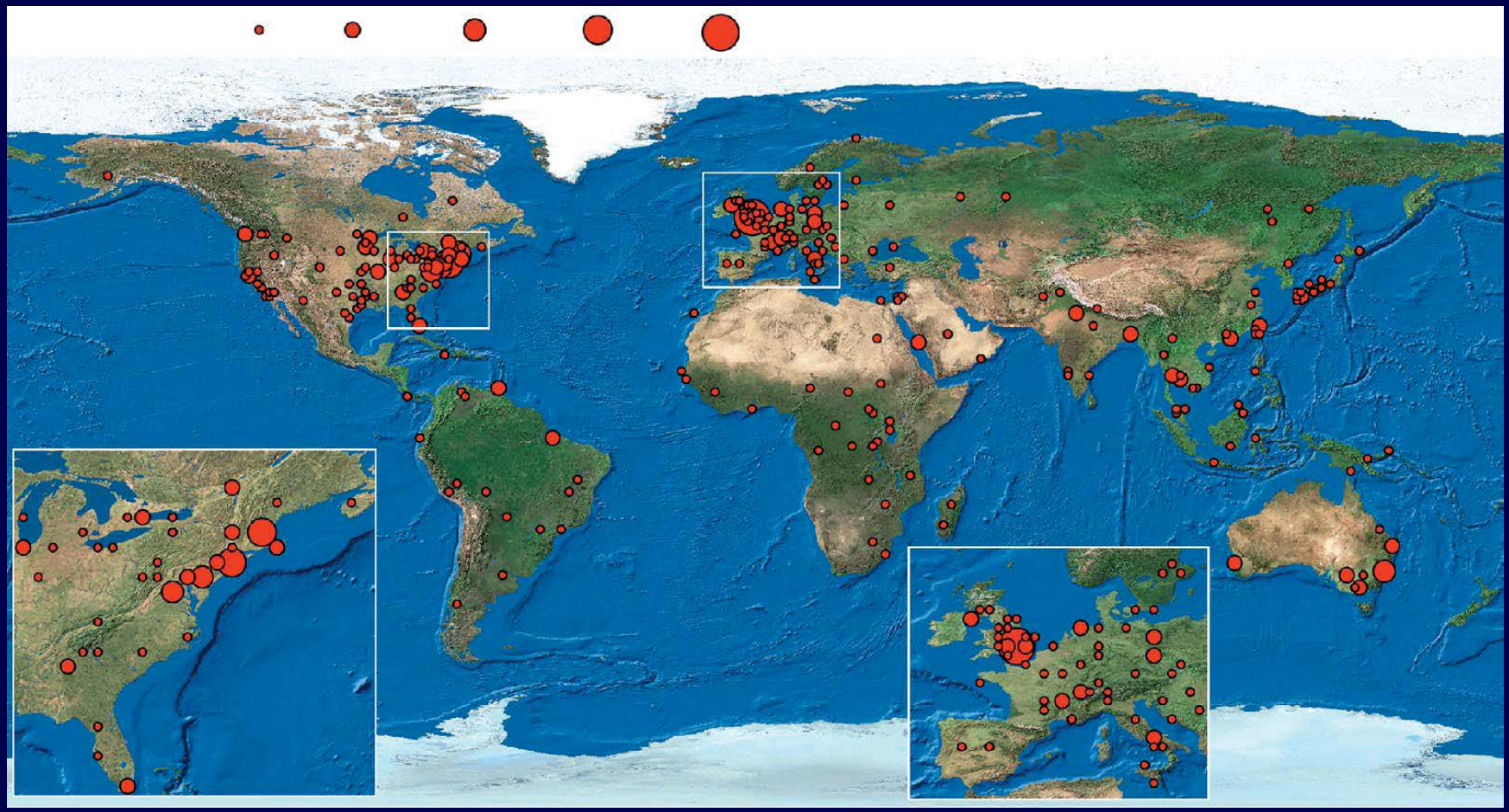
Water- and Air-borne Diseases Emerging at an Unprecedented Rate

- Challenges to US Clean Water & Safe Drinking Water Acts
- Parasites are crippling our economy & decimating our biodiversity
  - amphibians, bats, corals, and bees
  - ecosystem services
- Most emerging diseases are zoonoses
- Causes of increases in disease are often unknown




Emerging Infectious Diseases:

Not just a third-world problem!



Jones et al 2008-- Nature

Hypotheses between GCC and Disease Emergence

- Several folks propose links between GCC and disease emergence
- Most hypotheses have fundamental flaws
  - Based on mean changes to climate and optimal climatic conditions for host and parasites
- Few generalities have materialized for how temperature variability/extremes affect water and air quality.

Climate Variability Hypothesis

- Hypothesis: unpredictable temperature shifts, which are increasing with global climate change, benefit pathogens more than hosts.
  - faster metabolisms = acclimate more quickly to temperature shifts, especially for ectothermic hosts
  - fewer cells and processes to adjust
  - evolve more quickly to changes in climate

Summary

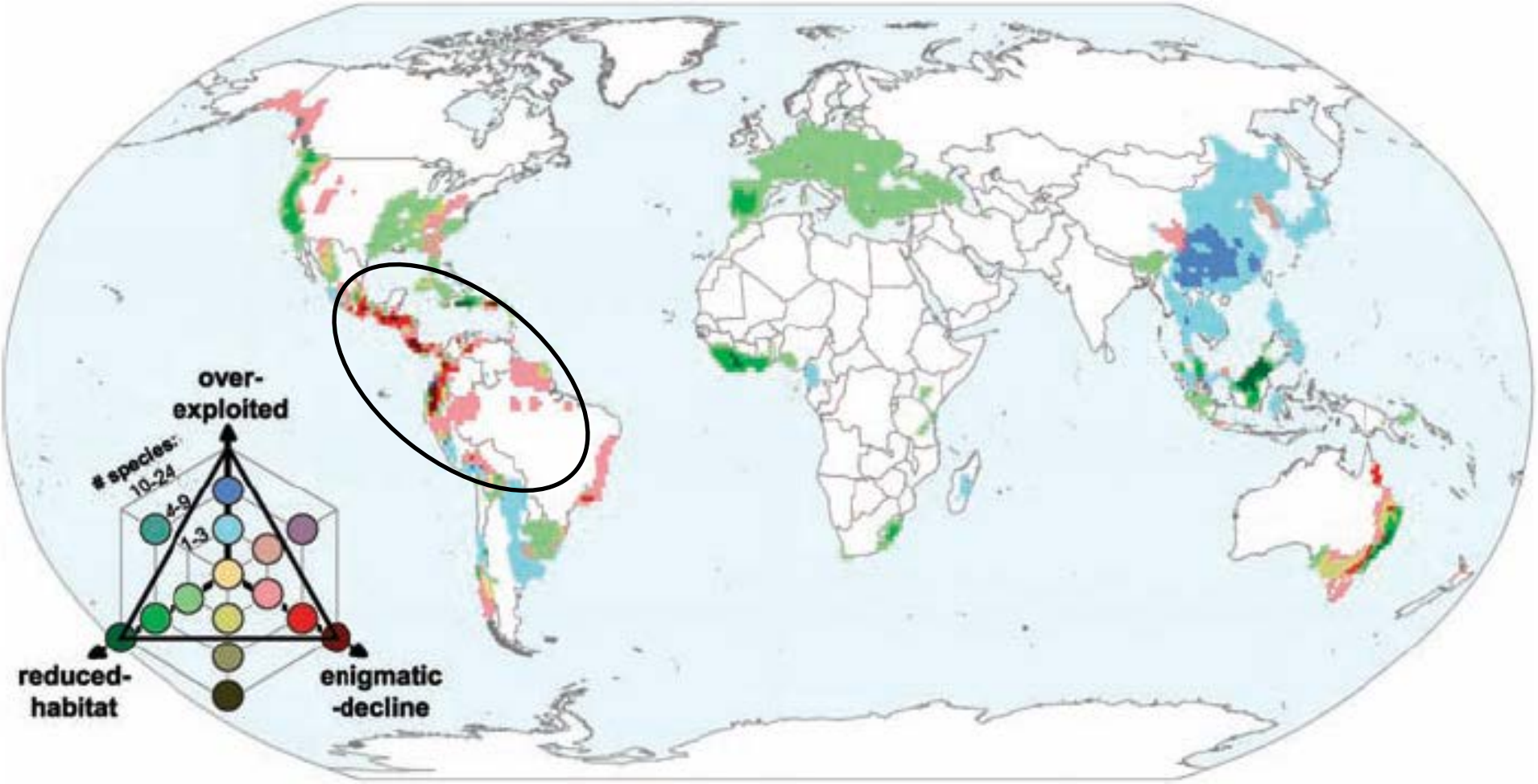
The categorically faster metabolisms, smaller size, and greater reproductive capabilities of parasites than hosts provides a general hypothesis for how global climate change will affect water quality and disease risk–

unpredictable climatic variability should reduce water and air quality by increasing pathogens

Model Disease: Chytridiomycosis

- Caused by the fungus *Batrachochytrium dendrobatidis* (hereafter referred to as *Bd*)
- Skin disease that likely causes cardiac arrest
- Implicated in hundreds of amphibian extinctions in the last four decades
- Possibly the most deadly invasive species on the planet behind humans

Enigmatic Amphibian Declines



Genus *Atelopus*

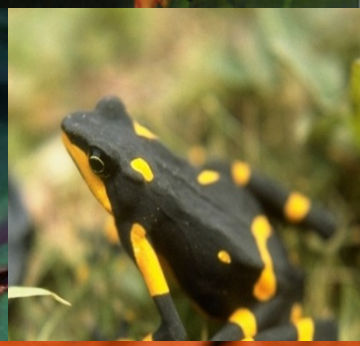




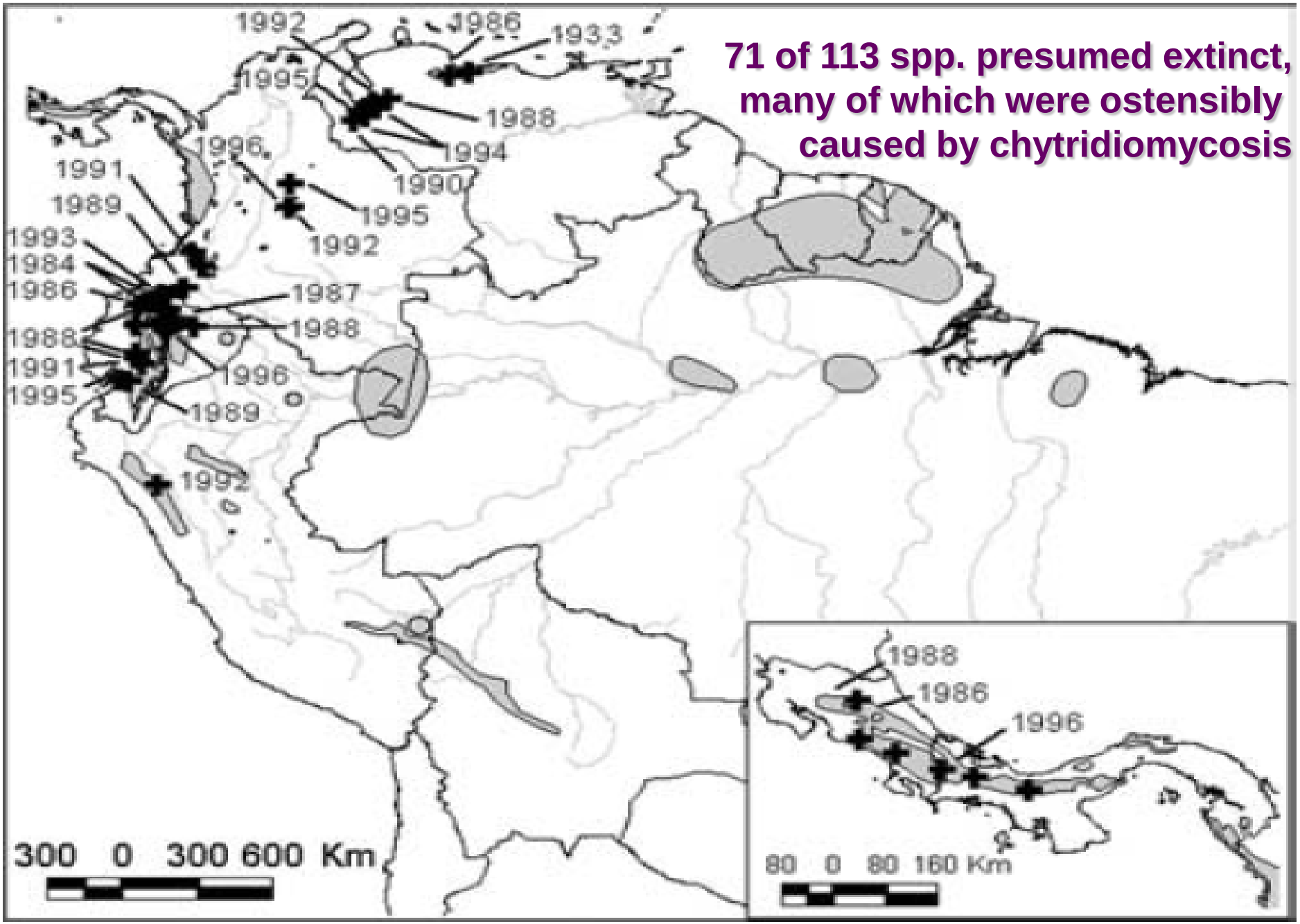






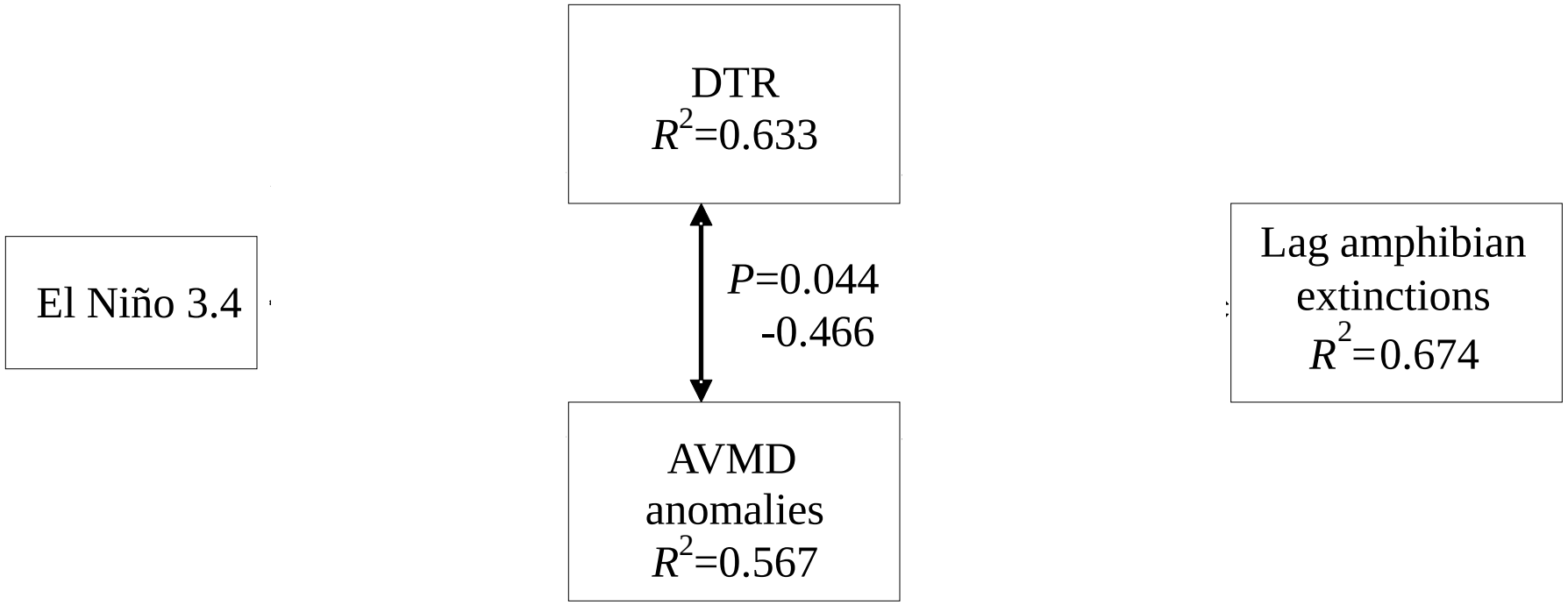




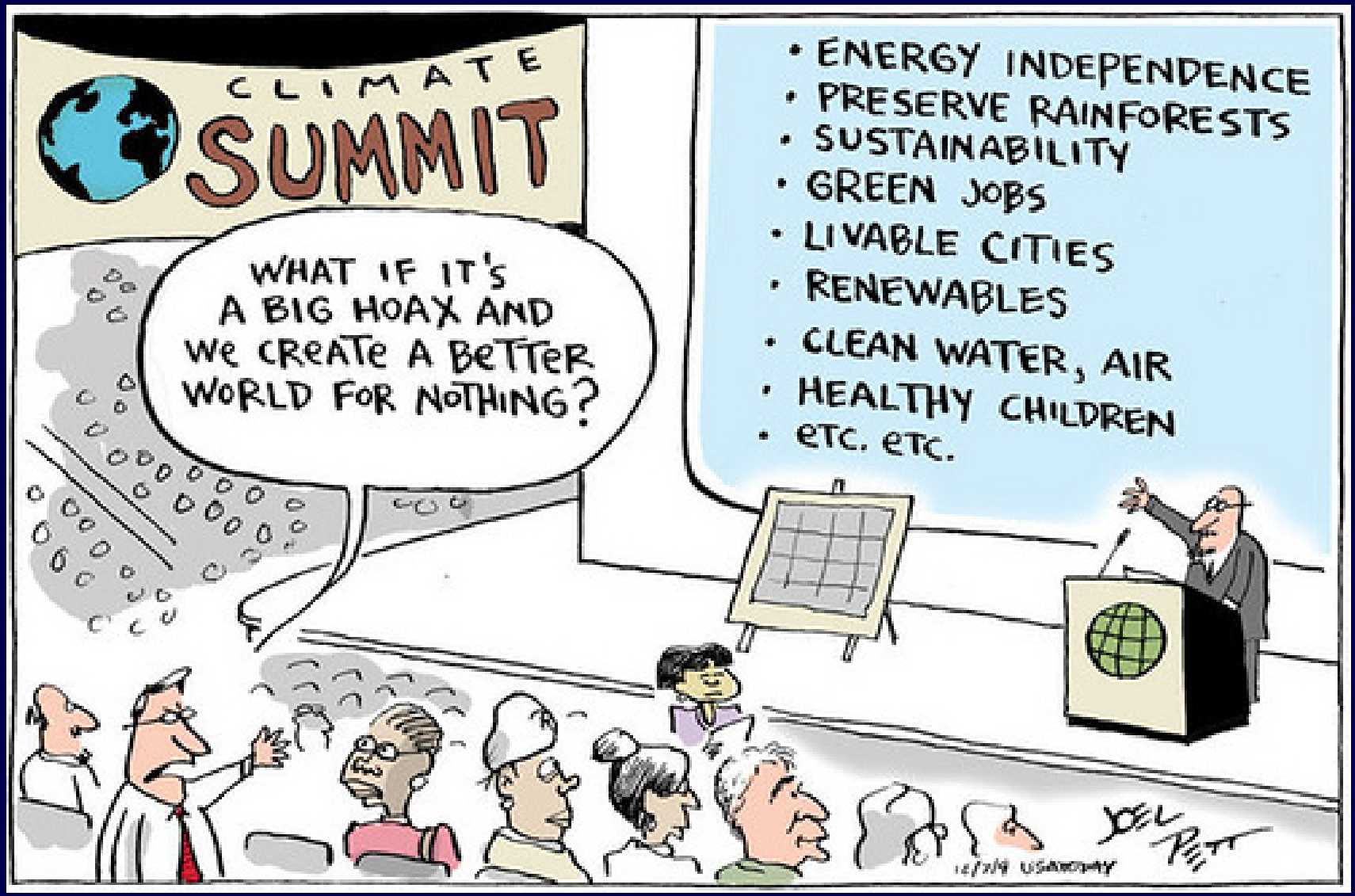
from La Marca et al. 2005. Biotropica

Rohr and Raffel 2010



Rohr and Raffel 2010
PNAS

We Weren't Convinced



Goals of Grant

Evaluate the hypothesis that extreme climatic events, which are increasing with GCC, facilitate the transmission of pathogens, thus compromising water quality.

Develop tools to predict how extreme climatic in a changing climate will affect disease risk from water-borne pathogens (our measure of water quality).

Specific Objectives of Grant & Outline for Talk

1. **Generality**: conduct experiments across host and pathogen types, including zoonotic pathogens
2. Dependence of disease transmission on the **temporal scale** and **predictability** of temperature shifts/extremes
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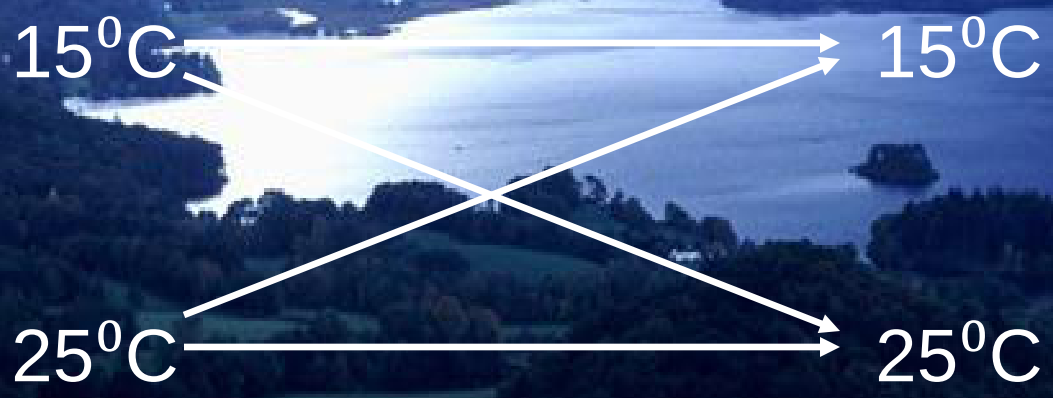
Experimental Test

- Acclimated Cuban tree frogs to 15 or 25^0 C for four weeks
- Challenged with *Bd, Aeromonas hydrophila*, or *Rhabdias* sp. at start of week five
- Quantified survival and pathogen loads

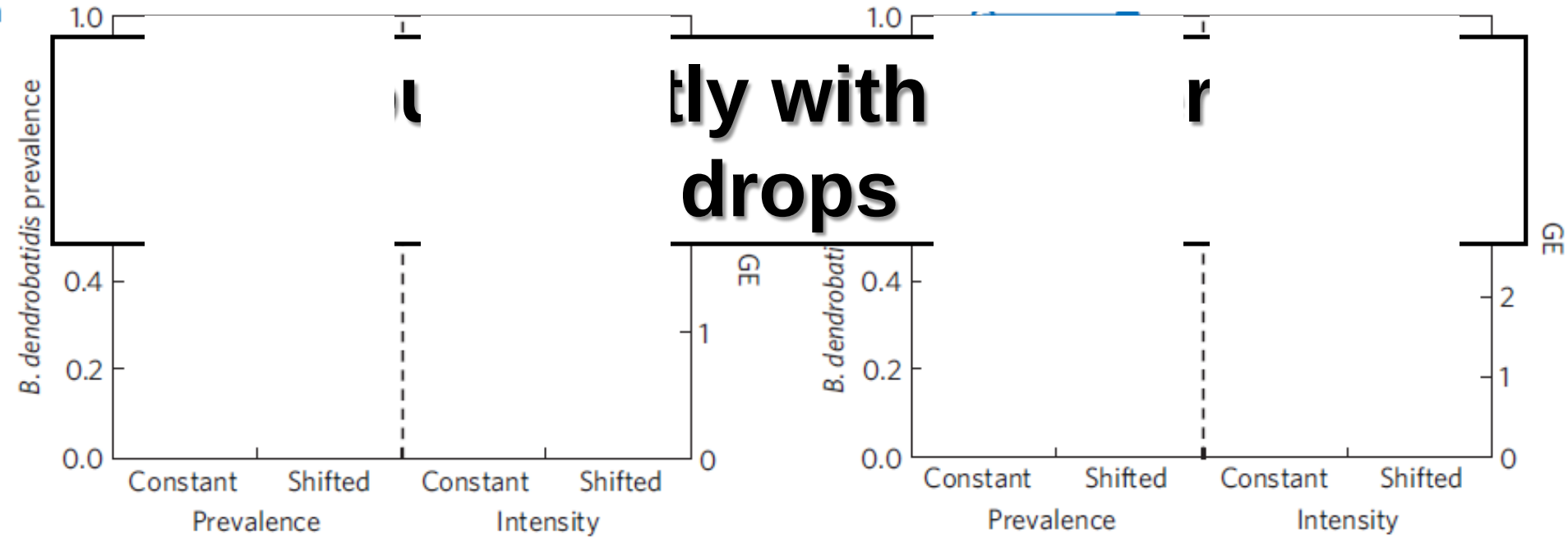



49
40
41


4 6 8 10 12 14 16 18 20 22 24 26 28 30

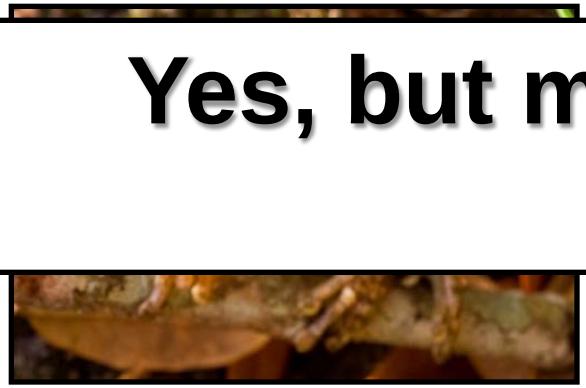
Does Temperature Variability Increase *Bd* Loads on Frogs?

***Bd* load on adults:** ***Bd* load on metamorphs:**

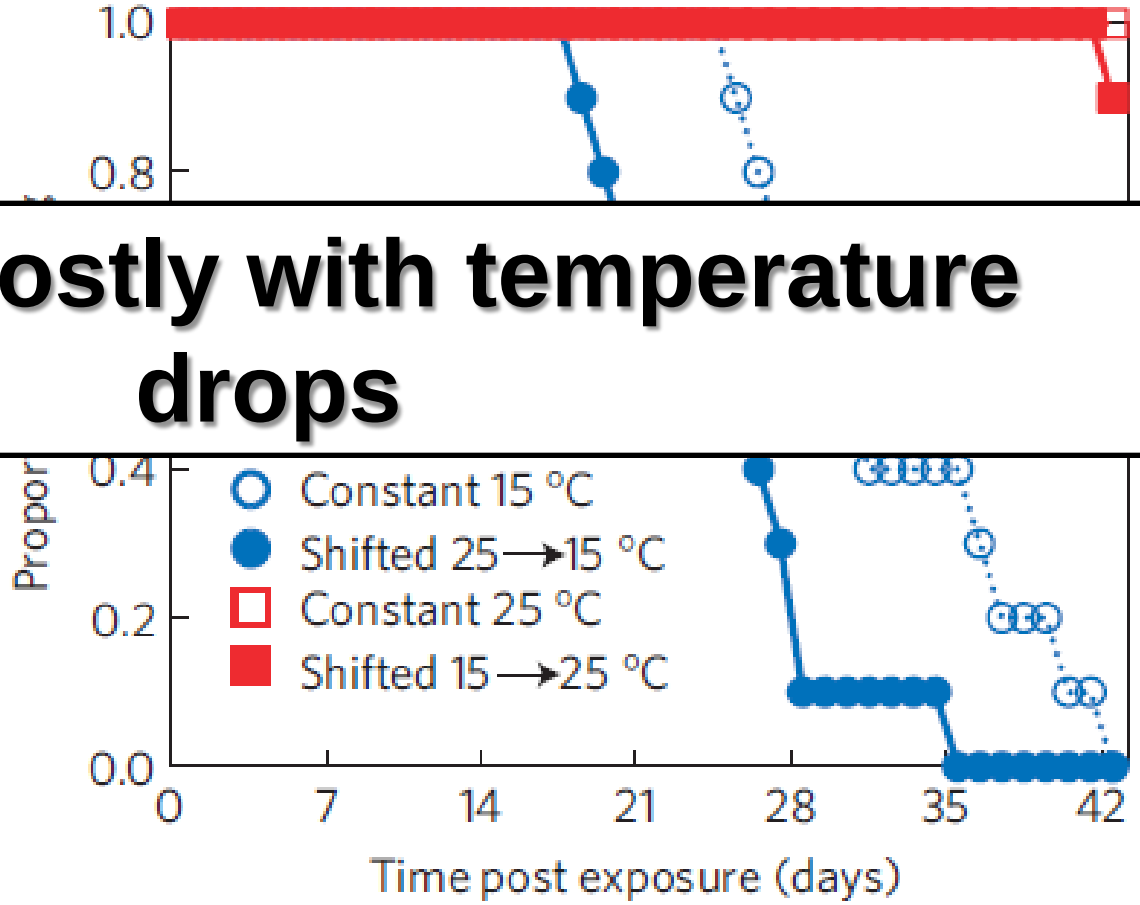


Raffel et al. 2013
Nature Climate Change

Does Temperature Variability Increase *Bd*-induced mortality?



Yes, but mostly with temperature drops



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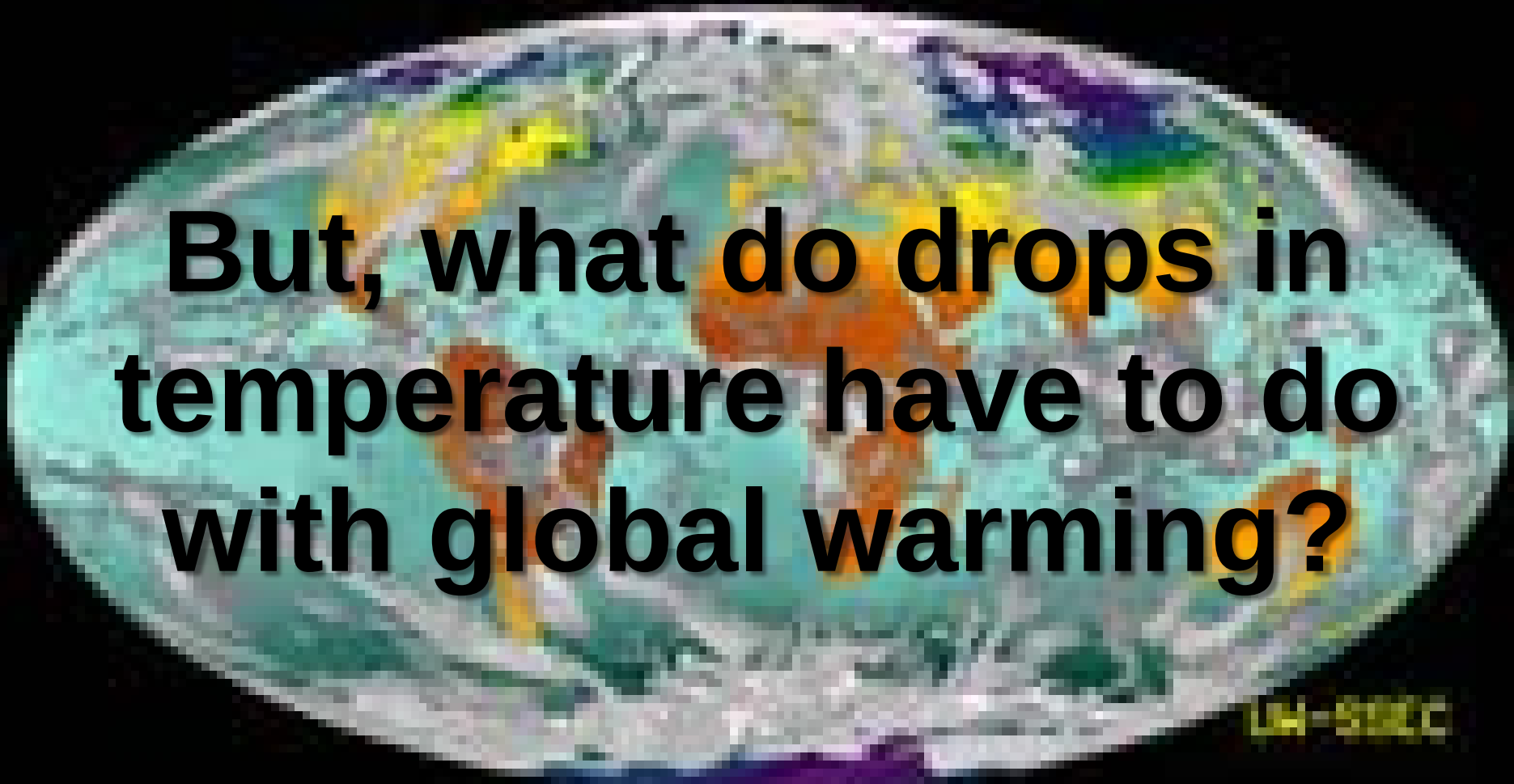
But, what do drops in temperature have to do with global warming?

Warmer years have significantly greater drops in temperature!

- Raising the roof means you have further to fall
- Consistent with global climate change as a driver of *Bd*-related declines

Does Temperature Variability Exacerbate Bacterial & Nematode Infections?

***Aeromonas*-induced mortality**	***Rhabdias* infection intensity**
In Progress	

Conclusions

- Elevated temperature variability might represent
  - a common, but under-appreciated, link between climate change and both disease and biodiversity losses
  - a general mechanism for why disease would increase with GCC

Follow-up Work on Generality

- Will conduct temperature shift experiments with three zoonotic pathogens: *E. coli* 0157:H7, *Salmonella enterica*, *Aeromonas hydrophila*

- Working with a global database on all fungal diseases to evaluate whether El Niño and variability generally increase outbreaks

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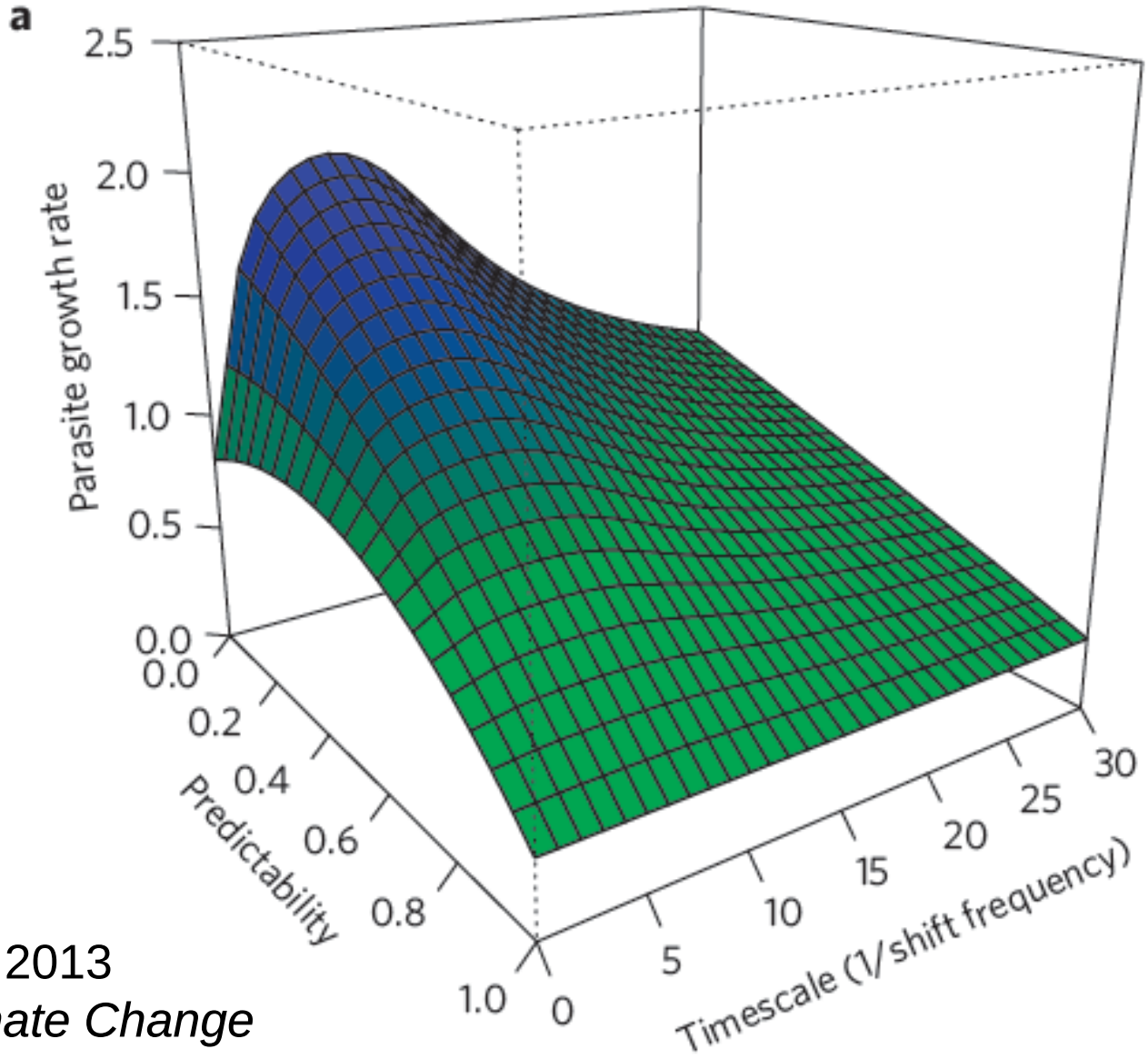
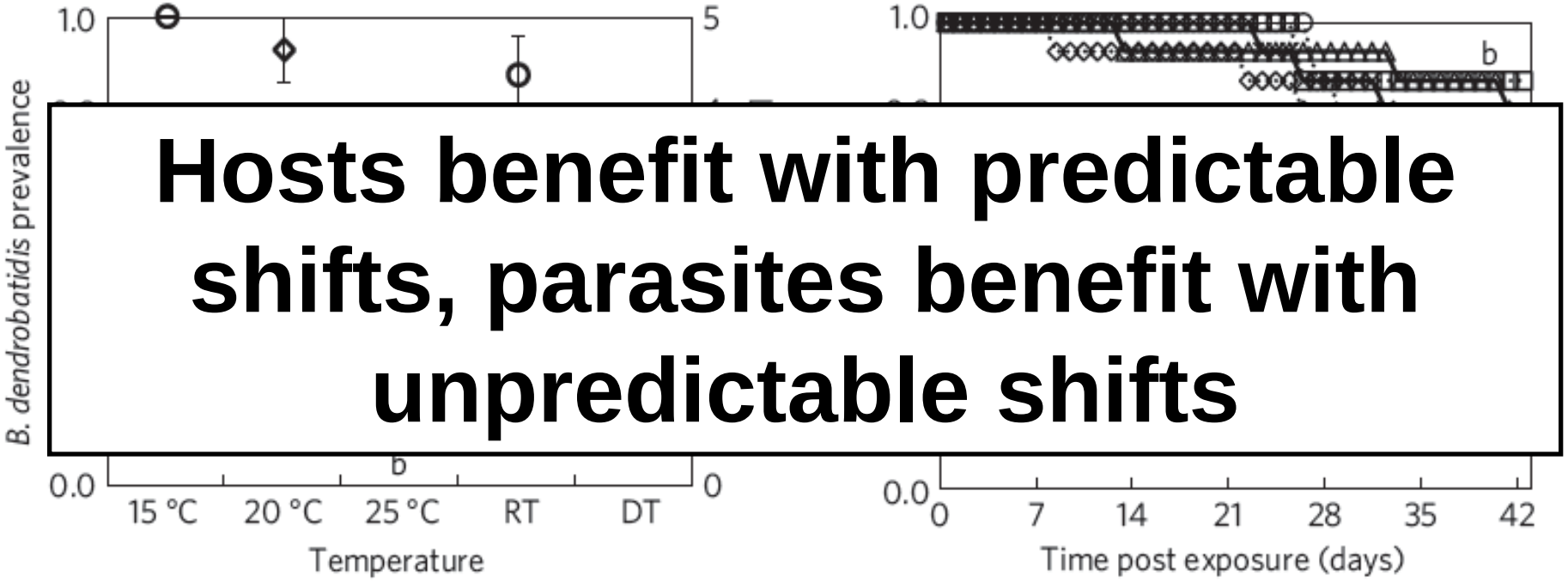
Model: Predictability & Time Scale



Raffel et al. 2013
Nature Climate Change

Predictability and Diurnal Shifts



Hosts benefit with predictable shifts, parasites benefit with unpredictable shifts

Raffel et al. 2013
Nature Climate Change

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Effect of Shift Depends on Moisture but Not Host Species

In Progress

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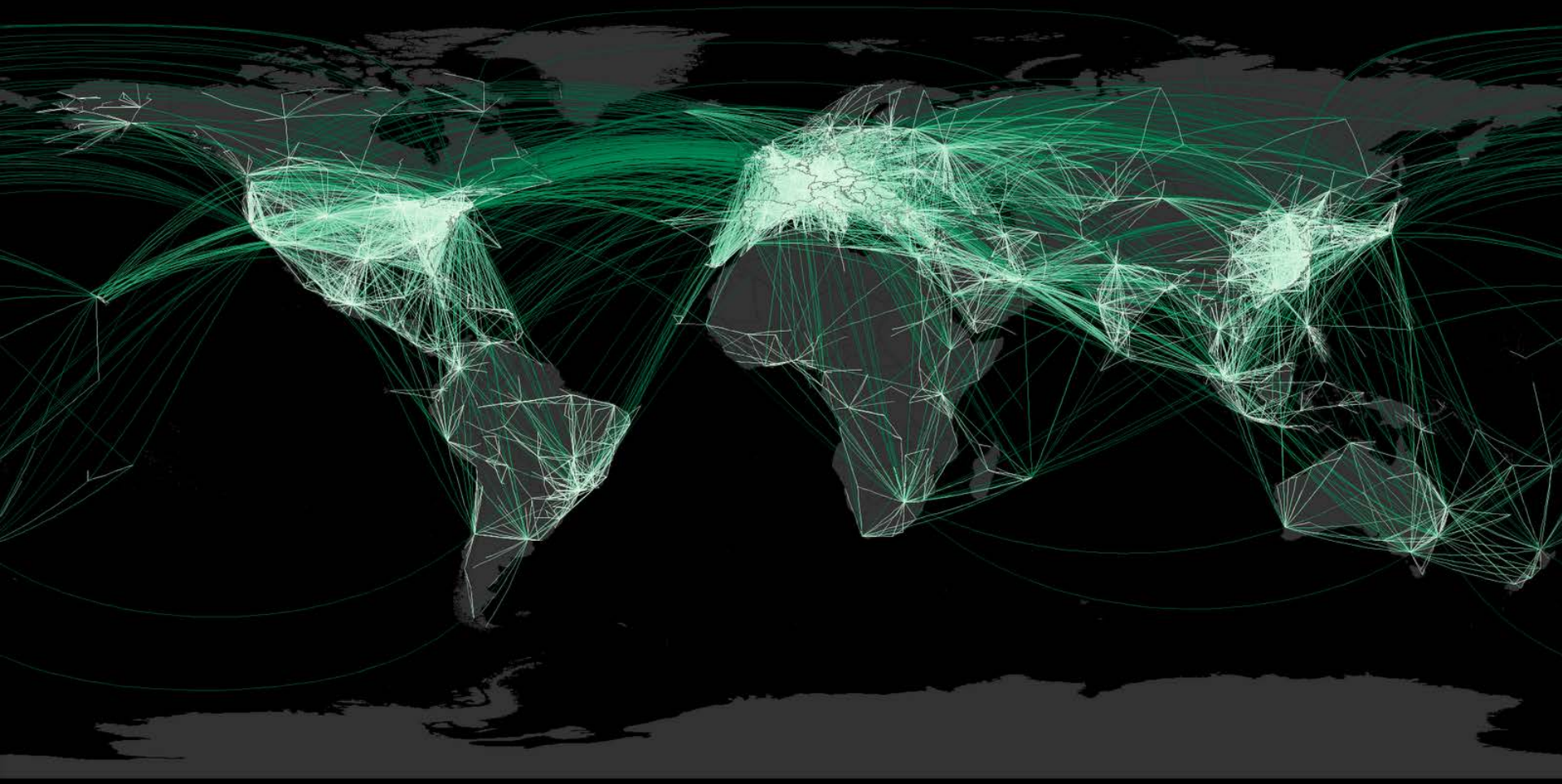
Cannot Ignore Human Movement



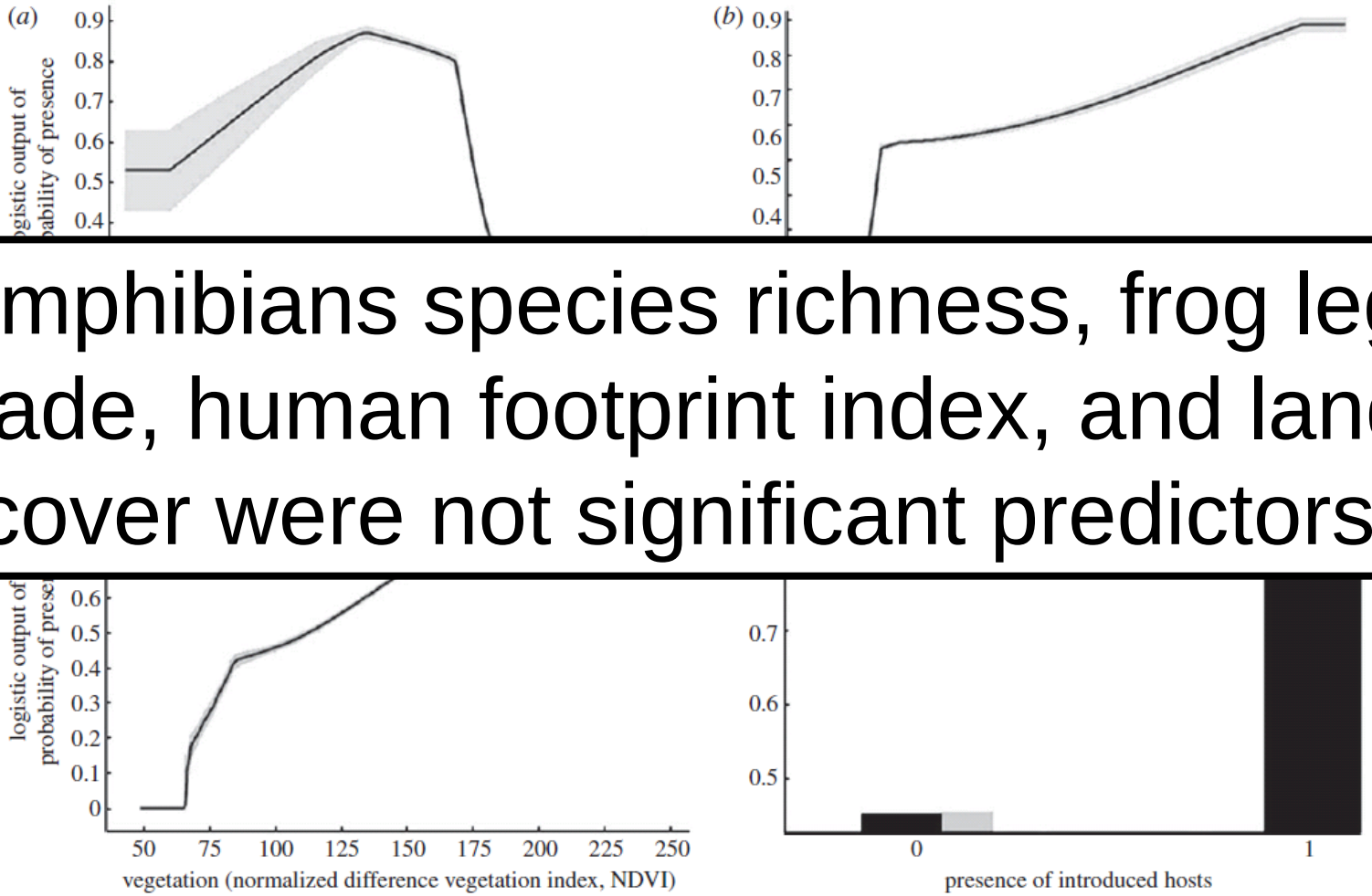
Global Distribution Model for Bd

Developed a global species distribution model for Bd using Maxent software and partitioned the variance between "fundamental niche" (FN, i.e. abiotic climate and habitat factors) and dispersal and "propagule pressure" factors (PP, number of non-native individuals released into a region)

Methods

- Gathered global Bd data from Global Bd-Mapping Project
  - >39,000 amphibians sampled, >3,800 sites, >80 countries, >1250 spp.
- 27 predictors classified as FN or PP; classification validated by PCA
  - 19 climate variables (FN)
  - Land use (FN)
  - Human footprint index (FN)
  - Vegetation index (NDVI; FN)
  - -- Amphibian specie richness (PP)
  - -- Introduced amphibian hosts (PP)
  - -- Frog leg trade (PP)
  - -- Global trade (PP)
- Minimized the effect of sampling bias by applying the FactorBiasOut and a bias grid methods
- Controlled for spatial autocorrelation
- Training and testing datasets for model validation

Results



Amphibians species richness, frog leg trade, human footprint index, and land cover were not significant predictors

Figure 1. Relationships between the probability of *Bd* occurrence and the four most influential predictors in the pruned fundamental niche and propagule pressure (FNPP) MaxEnt model: (*a*) annual temperature range, (*b*) trade, (*c*) vegetation (mean NDVI), and (*d*) presence of introduced hosts. Grey margins are ± s.d. based on 10-fold cross-validation replicates.

Liu et al. 2013 Proc. B

Significant Unique Variation Associated with Both FN and PP

Variance component	Adjust-R^2
Unique variation	
Fundamental niche (F)[a]	0.171
"Propagule pressure" (P)[b]	0.138
Spatial structure (S)[c]	0.102
Shared variation	
FP	0.159
FS	0.066
PS	0.095
FPS	0.06
Residual variation	0.209

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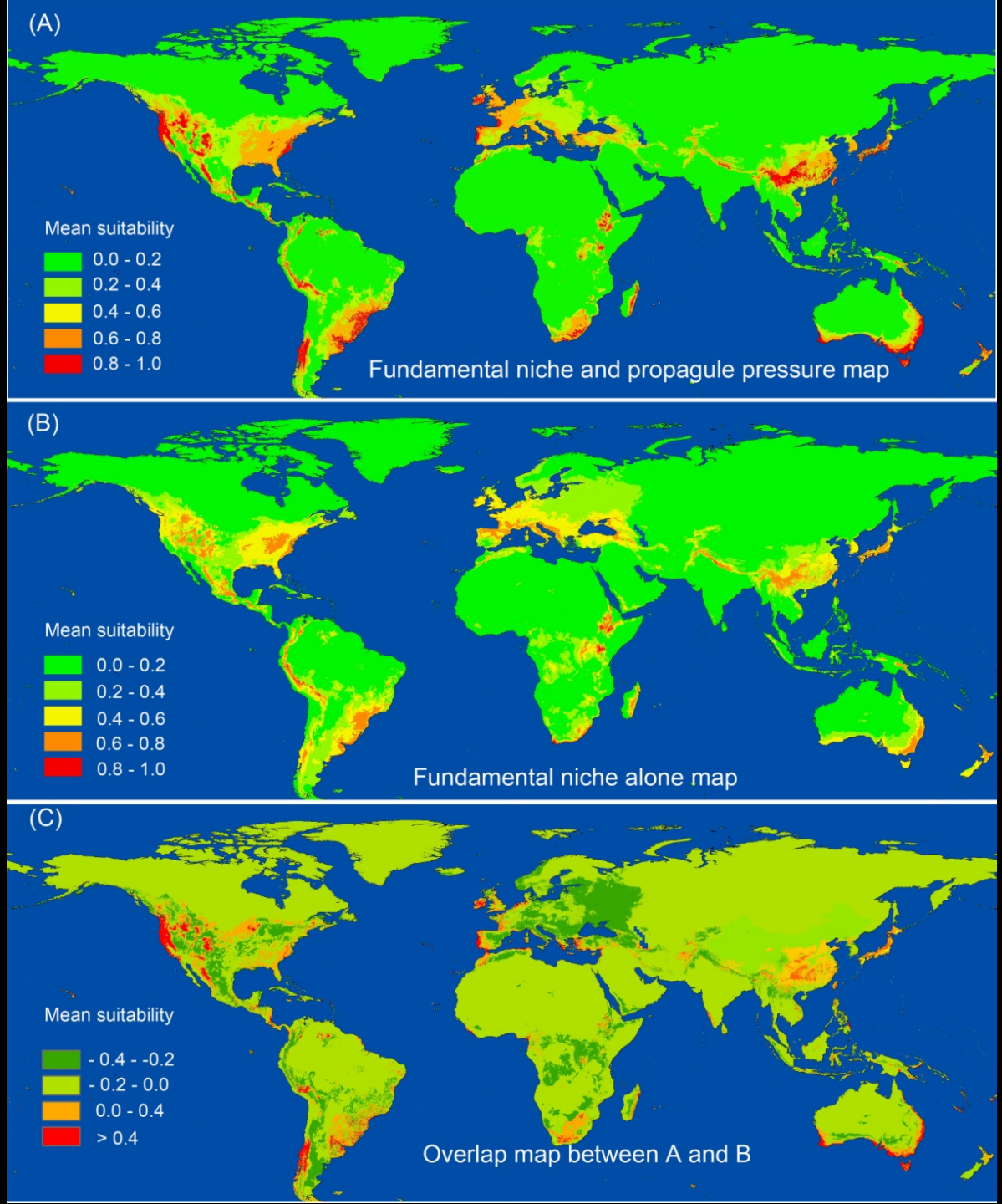

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2013
Proc. B

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Future Predictive Modeling

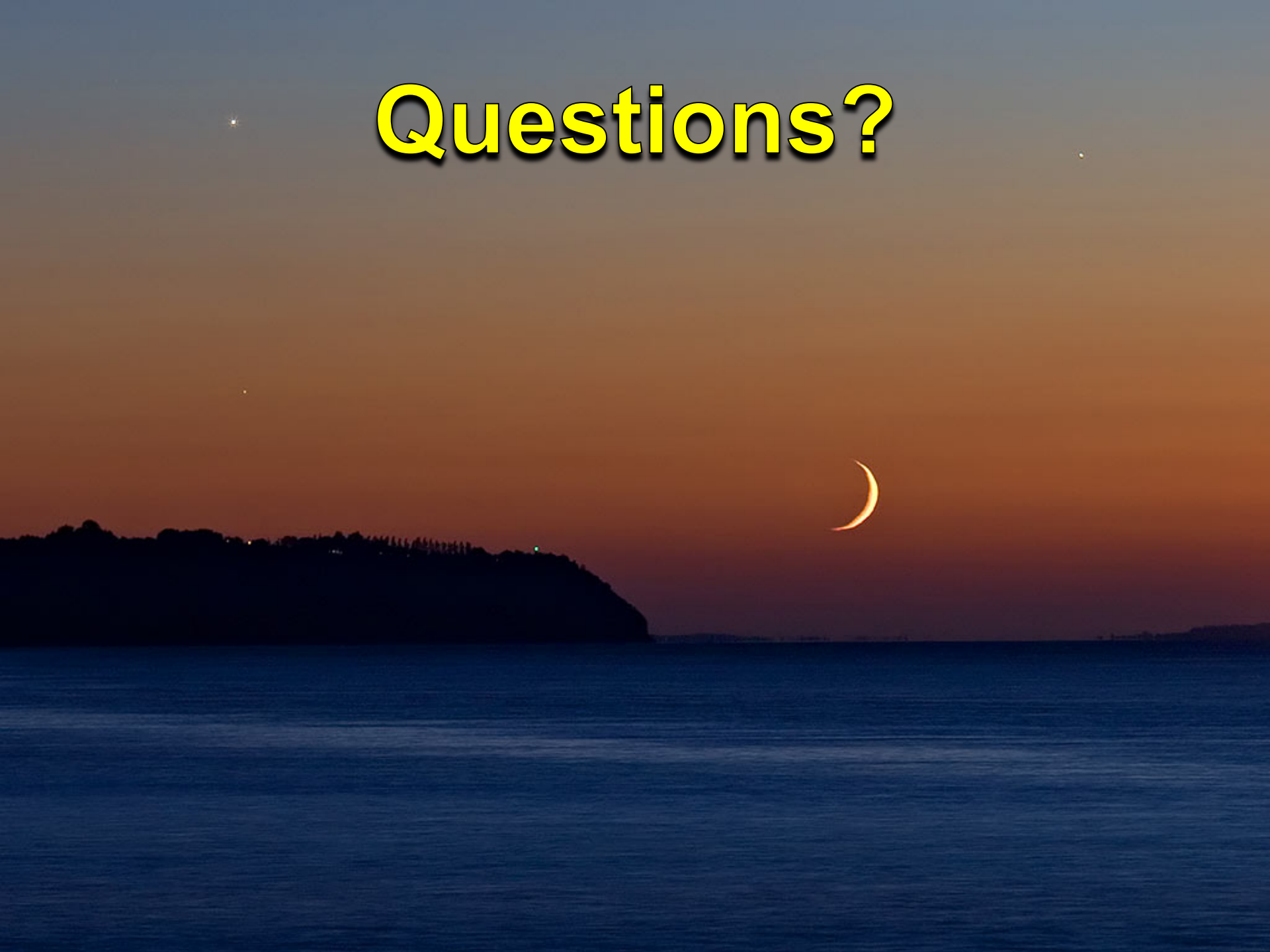
Need to assimilate all of our findings into regional ensemble models that consider various GCC scenarios and types of human and wildlife pathogens and complete model validations and uncertainty assessments.

Acknowledgements

FUNDING AGENCIES

Environmental Protection Agency

Graduate and undergraduate students, postdocs, and technicians that have assisted with this work


Questions?